

Appendix C Operation and Maintenance Considerations

C-1. General

To maintain operational capacity is a key consideration in the design of tainter gates. Operational capacity may be inhibited by various circumstances including normal deterioration due to corrosion and unintended loading (vibration, accumulation of ice, obstruction, etc.). Optimum operation can be assured by selection of appropriate design details and by providing continued maintenance and inspection.

C-2. Design Considerations

Tainter gate designs shall include provisions to minimize effects of corrosion and unintended loading and provisions to provide access required for inspection and maintenance. In addition to a protective coating system, corrosion can be controlled by appropriate detailing. Unintended loading is minimized by proper design of seal details, ice control, and trunnion lubrication. Bulkheads and safety devices provide access for inspection and maintenance.

a. Design details for corrosion control. Using continuous welds instead of intermittent welds, rounding sharp corners, and seal welding lap joints can minimize localized corrosion. Structural members should be located such that access for future inspection and necessary maintenance is provided. All areas should be visually accessible and provide access for inspection and painting equipment. For very large members, access manholes may be necessary. Provision for drainage should be included where water can accumulate such as on the webs of the girders, end frames, and bracing members. Drain holes should be located in areas that are lowest while the gate is in normal position. The size of hole is dependent on the size of drainage area and generally ranges from 25 mm (1 in.) to 75 mm (3 in.) in diameter. The cut edges of holes should be smooth and free of notches, especially in areas where the cut member is subject to tensile forces.

b. Control of unintended loading.

(1) Design details to control flow-induced vibration. Flow-induced vibration may occur due to flow under the gate or over the gate. Regarding flow under the gate, bottom seals of various configurations have been a source of vibration problems in tainter gates. This vibration can be minimized or eliminated with use of proper lip and bottom seal configurations as discussed in paragraph 3-7.a(2). (Other configurations are discussed in EM 1110-2-1605.)¹ The girder and bottom lip should be sized to have adequate stiffness to limit flexing that would permit flow between the lip and sill. Bracing of the cantilevered portion of the skin plate provides rigidity. Vibration (or debris) loading may also occur due to overtopping water and debris that may impact the upper girder. For conditions where this is a concern, deflector plates positioned to protect the upper horizontal girder will minimize the effects of impacting water and debris.

(2) Deicing systems. Devices for preventing the formation of ice, or to thaw ice adhering to the gates and seals, are necessary for gates that must be operated in subfreezing weather. Ice formation may freeze a gate in place or obstruct motion, and buildup of ice may add sufficient weight to overload gate hoists. Various solutions exist to control ice formation and buildup (Haynes et al. 1997). The most

¹ References are listed in Appendix A.

common methods of ice control for tainter gates are use of direct heating systems or air bubbler systems. Direct heating is the most effective means of controlling ice. Air bubbler systems for tainter gates are generally slow and inefficient; however, they may be beneficial when used to supplement direct heating systems where unusually severe climatic conditions exist.

(a) Direct heating systems. Direct heating units can be installed at appropriate locations on or around a gate. Generally, heater units consist of steel cells with embedded electric heating elements or heat tape with heat transfer fluid. Heating elements are generally helical formed coil of chrome-nickel, encased in a seamless sheath of corrosion-resisting, nonoxidizing metal. All heater units should be designed as removable units so replacement is easily accomplished. Side-seal heaters generally consist of a tubular steel cell with embedded heater elements that is fabricated to fit in a recess behind the side-seal rubbing plate along its length. Another method of heating the side seal is to heat the J-seal directly by inserting heat tape into the hollow portion of a hollow J-seal. The heated J-seal should be used to supplement embedded heaters, since the J-seal would prevent ice formation only along the J-seal, while the remainder of the side-seal rubbing plate could accumulate ice. Heat tape is discussed in EM 1110-8-1 (FR). To control ice formation on gate surfaces, box-type heater units can be attached directly to the downstream side of the skin plate and/or along the end frame members. These units are essentially flat rectangular steel cells that encase heating coils. The cells are sealed and insulated to direct heat to the gate surface. Radiant (or infrared) heaters provide another means to control ice on gate surfaces (Haynes et al. 1997). These heaters can be suspended in close proximity to the structure and may be practical in areas that are difficult to access.

(b) Air bubbler systems. Air bubbler systems are easy to use and can be custom designed for a particular project purpose to move ice and reduce ice growth. Bubbler systems consist essentially of compressed air circulated through a pipe system. Air can be released through outlets located in front of the gate sills to create a circulation of warmer water from the bottom of the reservoir toward the face of the gate. This will prevent the formation of ice on the face of the gate and tends to keep an area of open water upstream from the gates. Air bubbler systems are discussed in EM 1110-8-1 (FR) and Haynes et al. (1997).

(3) Lubrication. Lubrication of the trunnion is a primary design consideration. Lubrication reduces trunnion friction to minimize lifting forces and flexural forces in end frame members. The surface of the trunnion pin and bushing must be sufficiently lubricated for efficient operation of a gate. Lubrication can be accomplished by direct application of grease through the hub and bushing to the bushing-pin interface. Grooves are fabricated on the inside face of bushings to contain grease that is injected through holes drilled in the hub and bushing. Another option is to use self-lubricating bronze bushings.

(4) Debris protection. Unintended forces may occur due to accumulation of debris. Debris may become lodged between the gate and adjacent piers resulting in gate binding during lifting or may accumulate on gate members adding to the gate weight. Deflector plates can be attached to the end frame struts and on the downstream flange of girders at appropriate locations to provide debris screens. It is recommended that deflector plates be fabricated of abrasion resistant and lightweight material such as ultra-high-molecular-weight polyethylene.

c. Access.

(1) Temporary closure. Means to provide temporary closure between piers for emergency situations or gate maintenance or repair operations should be considered in design. In some cases, project operation may permit gates to be out of service for a known period, and temporary closure may not be needed.

Vertical lift gates and sectional bulkheads are the most common types of temporary closure structures. A discussion on maintenance and emergency closure facilities is included in EM 1110-2-2607. Maintenance bulkheads are generally provided upstream of tainter gates, and downstream if necessary, to accommodate unwatering between piers to provide a dry area for maintenance or repair activities. Since closure is for planned inspection and maintenance, maintenance bulkheads are designed for static heads and cannot be installed in flowing water. Bulkhead guide slots and sills should be located such that there is adequate space to permit the installation of maintenance scaffolding for use in maintenance and repair operations. Other factors that should be considered in determining bulkhead location are pier size and location and capability of bulkhead lifting equipment. The emergency bulkheads provide closure between piers under flowing conditions. Emergency closures can be provided upstream or downstream of the tainter gates; on many navigation projects, it may be advantageous to provide closure downstream of the service gate since many accidents involve barges on the upstream side. The decision to include emergency closure structures should be based on economic analysis of costs and associated benefits of emergency closure given a gate failure.

(2) Safety and critical items. Gate stops are attachments that provide a block to prevent a gate from being raised past the maximum elevation for safety and operational concerns. Gate stops are generally welded attachments that extend from the ends of the lower girder between the outside of the gate and the surface of the pier. When the gate is in the fully raised position, the stops contact stop beams that are mounted on the pier. To provide safe and easy access for inspection and maintenance, handrails and ladders may be attached to gate members using welded or bolted connections. The connections should be designed to minimize adverse effects (stress concentration, residual stress) on main structural members. Attachments should be located away from tension zones if possible and good detailing practice is essential.

C-3. Inspection

ER 1110-2-100 prescribes general requirements for periodic inspection of completed civil works structures that are applicable to all project features. Supplemental more specific requirements for inspection of hydraulic steel structures (HSS) are specified in ER 1110-2-8157. The structural engineer shall develop an inspection plan for each tainter gate in accordance with requirements of ER 1110-2-8157 and those specified herein. To conduct a detailed inspection for each tainter gate on a project is not economical, and detailed inspection must be limited to critical areas. The inspection plan should identify which elements require inspection and what nondestructive testing is required for each. The focus of an inspection should be on fracture critical members, and then critical members and connections most susceptible to various forms of degradation. Design drawings and computations, previous inspection reports and all operations/maintenance records since the most recent inspection should be reviewed to develop the inspection plan.

a. Identification of critical areas. The most critical elements are those that are determined to be fracture critical. Fracture critical elements are those that are subject to tensile stresses whose failure would cause the structure to collapse. Other critical structural elements include those that are most susceptible to degradation including fracture and corrosion.

(1) Fracture. Stress level, stress concentration, material thickness (affects residual stress, toughness, and constraint), quality of fabrication (i.e., weld quality, tack welds, intersecting welds, or poor accessibility), operational vibration or overload, displacement-induced secondary stress, and load distribution are each factors that may contribute to fracture. Fracture is most likely to occur at locations where high-tension stress and severe stress concentration exist. To identify critical areas for fracture,

locations of moderate-to-high nominal tensile stress level and details that include significant stress concentrations must be identified. The effects of stress level and sensitive details are combined to determine the critical areas for inspection. Stress levels are determined by appropriate structural analysis and the severity of stress concentration imposed by a particular detail is reflected by its particular fatigue category. Fatigue categories are specified in AISC (1994). Tainter gates generally have significant tensile stresses in the downstream flanges of the girders at the midlength (lower girders are more critical), in the upstream girder flange and the outside flange of end frame struts near the girder-strut connections, and where the end frames join the trunnion assemblies. Significant tensile stresses may also occur in end frame bracing members (due to trunnion pin friction), and in the upstream flange of skin plate ribs at the horizontal girders. For in-depth engineering inspections, critical areas that should be inspected for cracking are:

(a) Fracture critical components. Fracture critical components may include lifting brackets, lifting cable or hydraulic machinery components, various components of the trunnion assembly and trunnion beam, girders, and various end frame members. Fracture critical components may vary on different projects and shall be determined by the design engineer.

(b) Locations identified as susceptible to fracture or weld-related cracking. Trunnion weldments, trunnion girders (steel), lifting bracket weldments, the girder-rib-skin plate connection on the upstream girder flange near the end frames, the bracing-to-downstream girder flange connection near midspan, and the girder-to-strut connection are areas most susceptible to fracture. At intersecting welds and where previous cracks have been repaired by welding are also areas of concern.

(2) Corrosion. Corrosion can occur at any location on a gate; however, certain areas are more susceptible than others. Sensitivity to corrosion is enhanced at crevices, locations of dissimilar metals, areas subject to erosion, and areas where ponding water or debris may accumulate. Other areas that are susceptible to corrosion include where it is difficult to adequately apply a protective coating, such as at sharp corners, edges, intermittent welds, and locations of rivets and bolts. Corrosion-susceptible locations on tainter gates include trunnions with dissimilar metals, seal connection plates and rib-girder connections (crevice corrosion and dissimilar metals), locations of bolts (crevice corrosion), drain holes, and general areas where sharp corners, edges, and intermittent welds are located. Other areas where corrosion is likely to occur is where heaters are located and at the normal water line.

b. Inspection procedure.

(1) Inspection for cracks. Common nondestructive field methods to inspect for cracking include visual, penetrant, ultrasonic, and/or magnetic particle inspections. These and other methods are described in detail by ANSI/AWS B1.10 (AWS 1986). Visual examination is the primary inspection method and shall be used to inspect all critical elements. A visual inspection is “hands-on” and requires careful and close examination (particularly with the aid of a magnifying glass). Critical areas should be cleaned prior to the inspection and when necessary, additional lighting should be used. If cracks are suspected, penetrant, ultrasonic, and/or magnetic particle inspections should be used to confirm the extent of cracking.

(2) Inspection for corrosion. Appropriate tools that may be used to measure and define corrosion damage include a depth micrometer (to measure pitting), feeler gages (to quantify the width of a crevice exhibiting corrosion), an ultrasonic thickness gage (for measuring thickness), a tape measure, and a camera. Guidelines to quantify the severity of corrosion damage are given by Greimann, Stecker, and

Rens (1990). Nondestructive inspection techniques to inspect for corrosion damage include visual and ultrasonic inspections.

(a) Visual inspection. A visual inspection of all corrosion susceptible areas should be made to locate, identify, and determine the extent of corrosion. When corrosion is observed, the type, extent, and severity should be reported. Any failure of the paint system should also be identified. The extent of paint system failure and regions of localized discoloration of gate components should be recorded. In areas where paint failure has occurred, the gate surface should be visually examined for pitting. When pitting is present, it should be quantified by using a probe type depth gage following ASTM G46 (1994).

(b) Ultrasonic inspection. Ultrasonic inspection is useful to measure thickness loss and can be used to obtain a baseline reference for thickness when it is unknown. The thickness of a steel plate or part can be determined to an accuracy of approximately 0.13 mm (0.005 in.). The technique can be conducted through a paint film or through surface corrosion with only a slight loss in accuracy. Where only one side of a component is accessible, the open surface can be scanned to identify thickness variation over the surface to determine where corrosion has occurred. Ultrasonic inspection equipment may not be reliable when pitting corrosion is prevalent, because the size and depth of the pitting impair the output signal of the transducer.

(3) Operational components. Mechanical and electrical components including seals, lifting mechanisms, bearings, limit switches, cathodic protection systems, and heaters are critical to the operation of spillway gates and should be inspected appropriately. These components should be checked for general working condition, corrosion, trapped debris, necessary tolerances, and proper lubrication.

c. Inspection reports. Inspection reporting shall be in accordance with requirements of ER 1110-2-8157.